Overview of the Professional Fitting System

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INTRODUCTION

The Professional Fitting System (PFS) is designed to assist the clinician in patient testing, hearing aid and circuit selection, and fitting verification. It is a comprehensive resource for record keeping, hearing aid and circuit selection, and fitting verification. The PFS software specializes in nonlinear (compression) amplification and incorporates special fitting protocols to make the selection of compression parameters easier. PFS currently supports Starkey's line of custom and behind-the-ear programmable, and trimmer-controlled nonlinear processing hearing aids.

OVERVIEW

The advantage of compression amplification is to deliver the full auditory dynamic range of sounds to the patient whose dynamic range at some frequencies may be reduced because of sensorineural hearing loss. Nonlinear signal processing not only makes comfortable sounds loud enough to be perceived as comfortable, but also allows loud sounds and soft sounds to be perceived appropriately as well.

Although the auditory dynamic range can be predicted from available psychoacoustic literature (Pascoe, 1988) individuals may vary enough from average to make a difference in the selection of the required gain and output (Valente and Van Vliet, 1997). PFS offers both predicted and individualized measures of dynamic range. PFS will perform loudness growth testing automatically and has the capability to input individually measured loudness data obtained by other means. Furthermore, PFS will use average data developed by Seewald (1997) when individual results are not available (i.e. children or other patients unable to perform the loudness growth test). The loudness information is used to calculate the patient's auditory dynamic range and is utilized in the hearing aid selection and verification process.

In the last few years the proportion of hearing aids using nonlinear signal processing has grown (Kirkwood, 1997). Much research is in progress to determine the compression characteristics appropriate for a particular patient. During this period of technological growth, the methods used to fit the current generation of compression hearing aids as well as the concepts underlying compression amplification may be unfamiliar to many hearing professionals. Even when these concepts are used correctly, it can be difficult to translate the recommended compression characteristics into the selected hearing aid. PFS includes a program to assist the hearing professional in using the measured or predicted loudness growth data to identify the best matrix and parameter settings for a patient.

Once the preferred hearing aid, matrix and settings have been identified, the data can be sent to an order form screen. On this screen, the clinician may add or remove any options to customize the fitting. The order form is printed with bar codes for efficient and error-free data entry into the Starkey system.

PFS includes a real-ear measurement system to verify the hearing aid selection and to fine-tune the fitting. PFS calculates and displays multiple input level targets based on the loudness information obtained from the patient. Any of three currently used fitting protocols have been modified to work with the PFS software and can be used to calculate the targets. These protocols include: The Independent Hearing Aid Fitting Forum (IHAFF) (Valente and Van Vliet, 1997), the Direct Sensation Level [input/output] (DSL [i/o]) (Seewald et al, 1993; Cornelisse et al, 1995) and Fig 6 (Gittles and Niquette, 1995). The PFS identifies the DSL [i/o] protocol as FDR [i/o] to reflect the fact that not all of the original DSL [i/o] method has been

implemented. Although these protocols have been in use for a number of years, they have not been subjected to a systematic review and validation on a large, diverse hearing-impaired population. However, they are based on sound principles derived from relevant peer-reviewed research. The multiple input-level targets developed by these protocols are combined with the real-ear data to yield a very precise verification tool. The system can be used in real time to fine-tune the parameters not only to match real-ear targets but to match the patient's listening needs as well.

PFS also includes the Abbreviated Profile of Hearing Aid Benefit (APHAB) (Cox and Alexander, 1995): a 24-item questionnaire that asks the patient to judge the amount of difficulty he or she is having in each of four different environmental situations. These conditions refer to ease of communication (EC), the presence of background noise (BN), reverberation (RV) and aversive sounds (AV). PFS has software to take the patient through this test automatically or for the clinician to enter the results from the standard paper and pencil format. In either case, when measured before and after a hearing aid fitting, that is, aided and unaided, APHAB provides a measure of perceived subjective hearing aid benefit. An overview of the PFS components is shown in Figure 1.

HARDWARE

The PFS6000 system is Noah compatible or can operate as a stand alone system. It consists of the Professional Fitting System software, a complete hearing aid analyzer, a real-ear measurement system and basic database functionality to maintain patient files. It also includes Windows 95 software, a 17″ color monitor, a color inkjet printer, a probe microphone, a pair of ER 3A insert earphones, a loudness scaling keyboard, a main computer keyboard, couplers for all styles of hearing aids including completely-in-the-canals (CICs), a pair of conventional earphones and a self-contained cart to house the entire system.

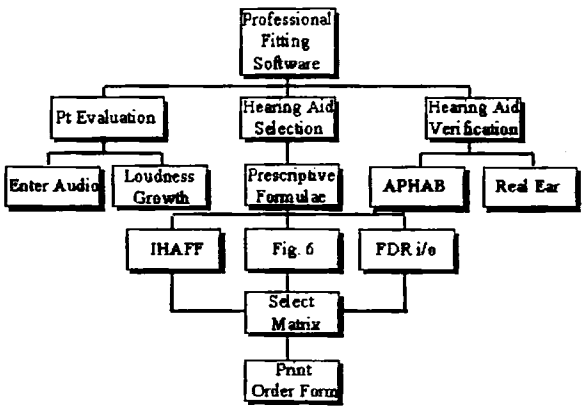

Figure 1. Components of the Professional Fitting System.

Programming is accomplished by means of a series of specially designed battery compartment interfaces which function as battery pill connectors (Figures 2a and 2b). The use of the battery pill eliminates the need for a battery during programming and the need for a separate programming access socket on the hearing aid. The result is a clean unobstructed faceplate.

BASIC OPERATIONAL SYSTEMS

Patient Information

PFS is designed to permit efficient and intuitive navigation through all functions and will alert

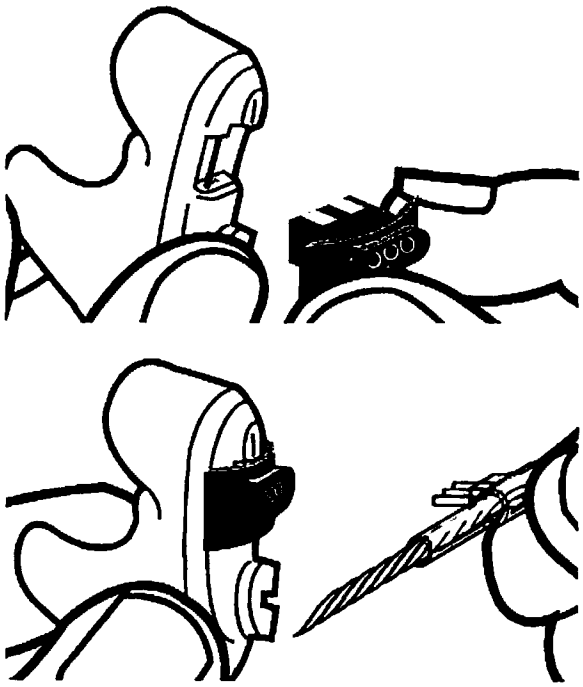

Figure 2a. Battery pill programming interface. The interface replaces the battery during programming. It inserts into the battery compartment after the battery door has been removed.

Figure 2b. Battery pill programming interface. A standard CROS cord is used as the connection between the battery pill and the main programming cables. For more details, refer to the PFS Operations Manual (Starkey Laboratories, 1997)

the user when specific information needs to be provided. PFS is designed to store and maintain patient data for those patients fitted using the system. When PFS is used with Noah, the patient data base and audiogram functions use the Noah framework. In the stand alone mode, new patients are added by entering information on the patient records screen (Figure 3). Records for previous patients are accessed through the data base search screen which is accessed through the Patient submenu. Once a patient has been identified, all subsequent operations are linked to that patient. If there is a need to change patients, the user is advised that patient data must be saved preventing the inadvertent loss of fitting information. Audiometric information is entered by the Noah audiogram or by means of the audiogram entry system of PFS (Figure 4).

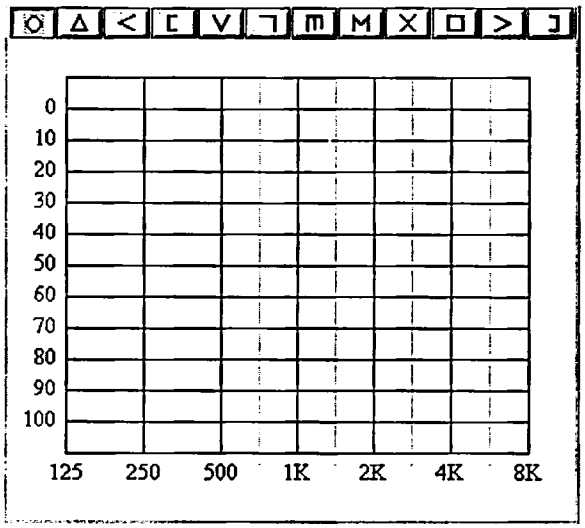

Figure 4. Audiometric data input screen

Audiogram

The audiogram contains the required information for PFS to calculate the appropriate settings for all hearing aid selection processes. To enter the audiometric information, click the desired symbol in the upper task bar and then click on the hearing level and frequency where the symbol is to be placed. LDL's data may be entered on the audiogram. The loudness growth test has provisions for manually entering loudness data. Audiometric data at 500, 1000, 2000, and 4000 Hz are used in the fitting algorithm to identify the best fit between the calculated target gain and the measured dynamic range of the patient.

Loudness Growth

The loudness growth test is available to assist the clinician in measuring the loudness dynamic range of the patient. The system is flexible to allow the clinician to conduct the test automatically or to enter previously obtained data. The loudness growth test is based on the Contour test developed at the Hearing Aid Research Laboratory of the University of Memphis and adopted by the Independent Hearing Aid Fitting Forum (Valente and Van Vliet, 1997). The data from this test can be used for both the IHAFF and FDR [i/o] fitting protocols. The Loudness Growth Test uses the seven loudness categories (Figure 5) developed by Hawkins et al (1987) and features a choice of ascending or random presentation methods. When the IHAFF introduced this test they indicated that both patients and clinicians prefer an ascending approach to loudness scaling rather than a random or descending method (Van Vliet, 1995). Starkey has included a random presentation method

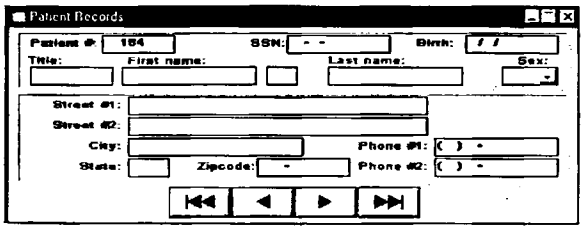

Figure 3. Patient data input screen.

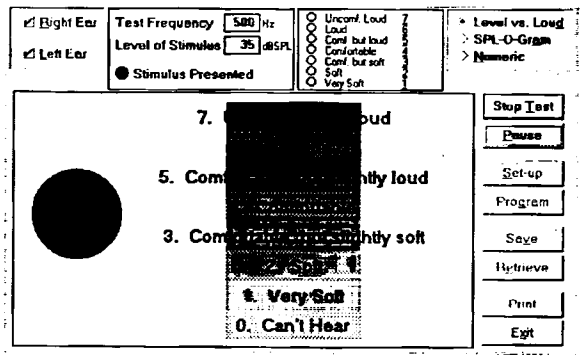

Figure 5. Loudness growth test. Loudness judgments are indicated by pointing to and "clicking" on the appropriate area of the screen using the computer mouse. Judgments can also be made using the numeric keys on the main computer keyboard or the scaling keyboard provided with the system.

because some reports show that patients may anticipate the very loud sounds and underestimate their actual loudness tolerance ability. In either case, the test uses a familiarization trial to allow the patient an opportunity to get the feel of the test and learn to use the computer systems. Once the test starts, the patient must make loudness judgments three times for each frequency. The loudness growth test uses the recommended stimuli and procedures outlined in the IHAFF protocol. The patient listens to three, two-second segments of warble tones using ER3A insert ear phones. After three trials, the system computes the median sound pressure level (ANSI, 1989) corresponding to each loudness level. The system also evaluates the data to make sure that the growth in loudness from one level to the next corresponds to an increase in sound pressure level. Data which show a decrease in SPL with a judged increase in loudness are flagged as errors. The clinician is afforded an opportunity to correct these judgments or to use average data instead.

To perform the loudness growth test the clinician instructs the patient according to the recommendations of the IHAFF protocol. In order to provide consistent and reliable results, a clearly written well-defined set of instructions is of critical importance. PFS uses the same instructions included with the IHAFF procedure (Hawkins et al, 1987). Once the patient has been instructed to the purpose and the mechanics of the test, insert earphones are put into place and the clinician starts the test. PFS will perform all signal generation functions including level and frequency changes. As the patient responds, PFS will automatically record the data and adaptively change the stimulus levels to assure that each stimulus was judged three times and that the loudness growth functions are monotonic.

Although the loudness growth test performs automatically, the clinician has a variety of options with which he or she can customize the test. The test will be performed only at 500 and 3000 Hz unless the clinician changes these parameters. These two frequencies were chosen for two key reasons. First, 500 Hz and 3000 Hz represent the two main areas of hearing where the effects of most sensorineural hearing losses are different. Low frequencies tend to present less hearing loss and a dynamic range closer to normal. High frequencies usually are the most affected by a hearing loss and have dynamic ranges which are typically narrower than normal. By measuring loudness growth for these two regions of the auditory spectrum, clinicians are better able to select compression characteristics and frequency responses more likely to compensate for the hearing loss. Second, the output, gain and slope of the matrix are calculated using 500 Hz and the peak of the frequency response which is 3000 Hz for the Sequel family of amplifiers as well as all class D amplifiers. The clinician can change the loudness growth test frequencies to any or all of the audiometric test frequencies. It should be pointed out, however, that matrix selection algorithms depend upon the relationship between 500 and 3000 Hz.

The clinician can also vary the step size of level changes used for the test. The standard step size is 5 dB. In some cases of very narrow dynamic range (i.e. if HL is 50dB or greater), a step of 5dB will be more than the loudness category range for which the patient must make a judgment. In this case, the 5 dB range will not have the resolution to accurately measure all of the loudness categories. In cases of narrow dynamic range, the step size can be changed to 2.5 dB. This will provide better resolution to the loudness growth function, but will increase testing time. A third option combines both step sizes by using 5 dB for softer sounds and 2.5 dB as the patient approaches the uncomfortable level (UCL).

The last procedural change the clinician can introduce is a random signal presentation protocol rather than ascending. The signal level is randomized within the test frequency. Three trials at each level are maintained as with the ascending method. A discussion of the differences in psychophysical method on the estimation of the loudness dynamic range can be found in Mueller and Bright (1994). The basic concept in all patient test procedures is consistency. Regardless of whether the ascending or random approach is used, the clinician must use consistent procedures and instructions to assure reliable results. The automated functions of the loudness growth test provide this assurance.

Loudness growth results can be displayed in three formats. The level vs. loudness scale display shows the loudness growth function for each frequency tested plotted on separate graphs (Figure 6). Each graph depicts the results for both the right ear (red) and left ear (blue) compared to normal (gray). The SPL-O-Gram display plots the loudness contours for each across the frequency range tested (Figure 7). This display shows the SPL associated with each loudness category across frequency. The result is a contour describing how each loudness category varies as a function of frequency. The bottom contour shows the Hearing

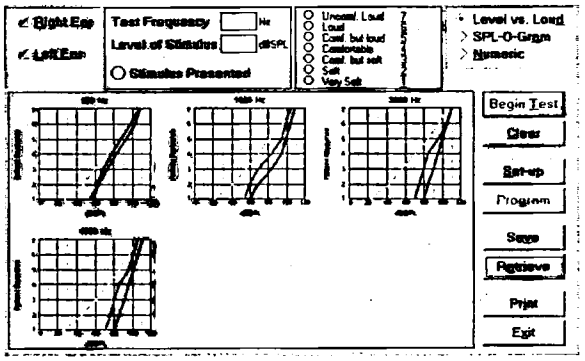

Figure 6. Loudness growth test results in the Level vs. Loudness display.

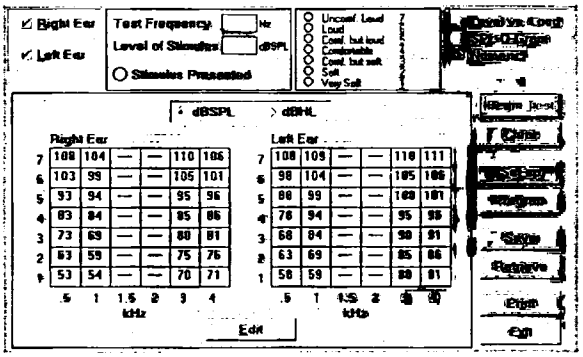

Figure 8. Loudness growth test results in the numeric display. This display allows manual entry and editing of data in either SPL or HL values.

Threshold Levels taken from the audiogram. Finally, the numeric display shows the actual value of each loudness scale category in either dB SPL or dB HL (Figure 8). The numeric display will also permit the manual entry of loudness data. This is extremely useful in cases where the patient cannot complete the automatic loudness growth test or loudness scaling data have been obtained elsewhere. These data can be entered in the appropriate cell of the numeric display in either HL values or SPL values. Conversion between the two scales is automatic.

Hearing Aid Selection

The Professional Fitting System's primary function is to assist the clinician with selecting and verifying the fit of hearing aids with nonlinear signal processing. The PFS uses nonlinear protocols and specialized search algorithms to match coupler and real-ear targets with the appropriate base matrix and parametric settings. This process chooses a "best fit" recommendation for the clinician's review and establishes a method for real-ear and coupler verification of the fitting.

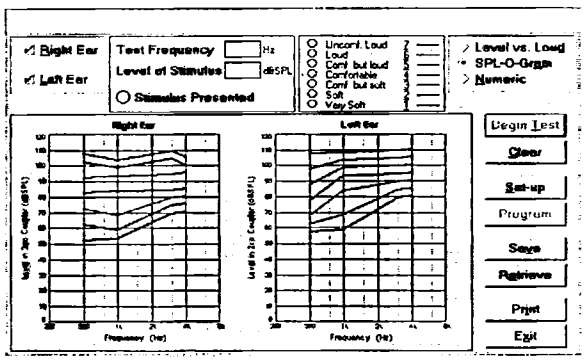

Figure 7. Loudness growth test results in the SPL-O-Gram display.

Creating Coupler Targets

The PFS uses three of the most recent fitting protocols for nonlinear hearing aids. These protocols have been modified to enable the development of 2cc coupler targets and to permit a search of available parameters to match these targets. Once matched, PFS interprets the match into base matrix and trimmer positions which are displayed for the clinician. Since all of these fitting protocols have not yet been completely validated and are still in the early stages of their development, the PFS allows the hearing professional complete control over the selection of the base matrix and the setting of the programmable trimmers.

IHAFF

The IHAFF protocol attempts to normalize the relationship between environmental sounds and loudness perception. Thus, a sound that is perceived as soft to someone with normal hearing should also be perceived as soft, after amplification, to a person with hearing loss. This holds true for comfortable and loud sounds as well.

The IHAFF protocol is not designed to recommend a hearing aid matrix. It is designed to display a set of input-output (i/o) functions which would compare the target i/o function at a single frequency to compression ratios, compression kneepoints and output parameters manually entered into the Visual Input-Output Locator Algorithm (VIOLA) menu of the IHAFF software by the clinician. The accuracy of the match is dependent

upon the amount of information the clinician enters. It also requires loudness data developed from loudness growth testing (i.e. the Contour test). A full description of the IHAFF protocol can be found in Valente and Van Vliet, 1997.

FDR [i/o]

The FDR [i/o] protocol is based on the DSL [i/o] approach developed by researchers at the University of Western Ontario (Cornelisse et al, 1995). DSL [i/o] is designed to place amplified speech into the residual dynamic range of the hearing impaired listener. The method involves specifying the desired output characteristics of a hearing aid for a range of inputs. It relates the electroacoustic characteristics of a hearing aid to measures of a patient's residual dynamic range; the levels between hearing threshold level and the upper level of comfort. The entire DSL [i/o] program is a self-contained hearing aid selection system. In PFS, Starkey has utilized only the portions which calculate the compression threshold and compression ratio needed to fit the normal range of sounds into the residual auditory area of the hearing impaired patient. The PFS calculates the multiple targets, the various input levels, frequency responses and frequency specific i/o functions based on this relationship.

The IHAFF and FDR [i/o] protocols utilize the loudness data obtained by the loudness growth test. It is also possible to utilize predictive values in place of individually measured loudness growth data in cases where the clinician is unable to obtain this information. For some patients, the ability to accurately judge and scale the loudness of warble tones is beyond their capabilities. In these cases, the residual auditory dynamic range can be estimated from the hearing threshold levels. The PFS uses the tables developed by Pascoe (1988) which relate the threshold of discomfort to the hearing threshold levels for adults. Thus, in those cases where actual loudness information is not obtained, the hearing threshold level is used as the start of the loudness growth function (level 1 - very soft) and the calculated UCL based on the Pascoe data is used as the upper end of the loudness growth function (level 7 - uncomfortably loud). The other loudness categories are linearly interpolated and become the final predicted loudness growth function.

Fig6

The Fig 6 (Killion, 1994; Gittles and Niquette, 1995, Killion, 1996) procedure is a threshold-based calculation designed to estimate the level-dependent, frequency-specific gain of nonlinear hearing aids. The required gains for soft (40 dB SPL), comfortable (65 dB SPL) and loud (90 dB SPL) sounds are calculated for each frequency based on the estimates contained in Figure 6 of Killion and Fikret-Pasa (1993). Fig6 uses average data which relate auditory thresholds and equal-loudness contours. These estimates are based on the data of Pascoe (1988), Lippman et al (1981), Lyregaard (1988) and Hellman and Meiselman (1993). PFS uses the 2cc coupler targets for soft, comfortable and loud sounds developed by Fig6 to select the "best fit" matrix, and to create multiple input-level targets for real ear fitting and verification.

Using Nonlinear Fitting Protocols for a "Best Fit"

The PFS uses a modified version of the IHAFF, FDR [i/o], and Fig6 protocols to select a base matrix (output, gain and low frequency slope) as well as compression threshold and ratio which match the computed targets. The resulting selection is displayed against simulated 2cc coupler targets derived from the computations (Figure 9a). The graphic display shows the prescribed frequency response, i/o functions for each frequency tested as well as multiple targets measured in 2cc coupler for inputs of 50, 70 and 90 dB SPL. The clinician can vary the hearing aid parameters by rotating the software trimmers and by selecting a different base matrix to see if they can achieve a better "match".

The Standard display (Figure 9a, upper right box) of target and hearing aid data includes i/o functions for 500 and 3000 Hz (upper graphs) and the simulated frequency response (lower graph). Figure 9b shows the display for real time adjustment, accessed when the "Adjust On" button is "clicked". These displays will show the loudness data for each frequency tested. In this case data are shown for 500 Hz and 3000 Hz as these were the only frequencies tested. The targets are derived from the fitting rule selected by the clinician (see box to the right of the loudness growth curves, where, in this case the IHAFF rule was selected). The frequency response of a proposed hearing aid selection is generated from the automatic selection of the proper microphone, receiver, amplifier and trimmers from within a database of specifications for these specific components. The "target" simulated frequency response represents full-on gain as measured in an HA-2 2cc coupler with 50 dB input and is shown with a ± 5dB

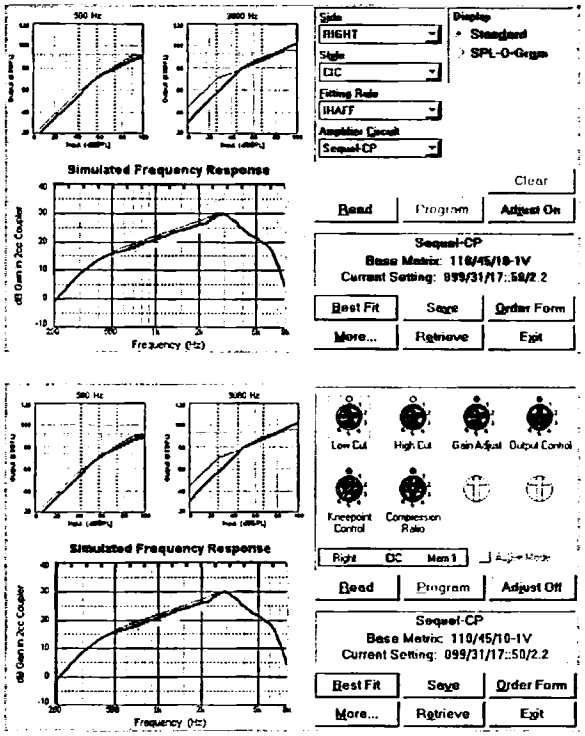

Figure 9a. Example of a "Best Fit". In this example a programmable CIC for the right ear is analyzed using the IHAFF protocol and loudness growth test data. The upper graphs show input/output functions for 500 and 3000 Hz (bold lines) along with the IHAFF targets for those frequencies (thin lines). The shaded areas represent the IHAFF categories of soft, average and loud speech. The lower graph is the frequency response (bold line) based on the programmable settings (see figure 9b). The IHAFF target is shown (thin line) with a range of ±5 dB (shaded area).

Figure 9b. Example of a "Best Fit". The programming parameters are accessed by "clicking" on the Adjust on/off button. In this example, six programmable features are available as shown.

range. In this example, the IHAFF protocol has been selected, and thus the shaded areas on the i/o functions represent the areas of soft, average and loud speech based on the results of the loudness growth tests or the use of average data as described previously. When the FDR [i/o] rule is used, the shaded area represents the dynamic range of the patient above which is the area representing the level of discomfort. Shaded areas are not used with the Fig 6 protocol.

SPL-O-Gram Display

The SPL-O-Gram display (Figure 10) shows the same data as the standard display (Figures 9a and 9b). In this screen, the data represent the simulated output measured in an HA-2 2cc coupler that the hearing aid will produce with inputs of 50, 70 and 90 dB SPL. This display demonstrates the compression characteristics of the hearing aid matched against the level-dependent targets derived from the selected fitting protocol. In the display the hearing aid response is shown as a bold trace and its associated target is a fine trace.

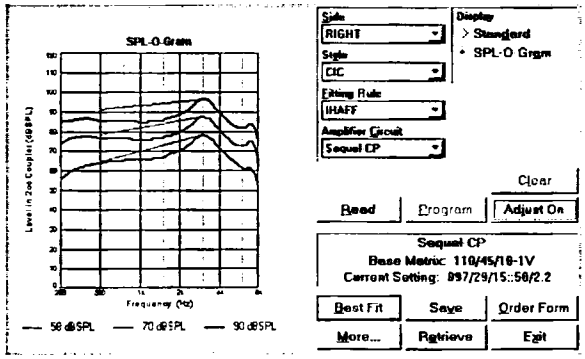

Figure 10. Example of a "Best Fit" using the SPL-O-Gram display. The same result shown in Figure 9a and b is displayed as outputs (bold lines) based on inputs of 50, 70 and 90 dB SPL. The IHAFF targets for each input level are shown for each input (thin lines). As shown in figure 9b, the adjustment controls can be accessed by "clicking" the Adjust on/off button on the right.

Binaural Fittings

The PFS creates binaural fittings by averaging loudness data between the ears. It does not adjust the gain to compensate for binaural summation, reserving that function for the hearing professional. The system will allow the binaural function only when the difference between ears is less than 10 dB for the audiometric test frequencies and loudness growth data. If this 10 dB criterion is not met, the PFS expects each ear to be fit on the basis of individual ear information.

Selection Process

Once the target is computed and the style and type of hearing aid is selected by the clinician, the PFS will search for the hearing aid characteristics that best match the targets. In general, priority is given to matching the gain in the region of 500 and 3000 Hz while at the same time maintaining the trimmer settings at mid-range. Priority is also given to the compression ratio and gain controls

to maintain these in the mid-range as well. This process permits a fitting with the flexibility to increase and decrease the hearing aid response within the range of the custom designed matrix. The PFS uses a base matrix for its programmable custom hearing aids rather than permit a single circuit to be varied across the entire range of gain and output. This permits the selection of the proper microphone and receiver combination that is best for the size of the hearing aid and its amplification requirements.

Best Fit

When the clinician clicks the "Best Fit" box on the screen, the PFS will compare target values to the actual specifications in the database (Figure 10, lower right) The search takes about 10 seconds and the data are displayed in either the Standard or SPL-O-Gram formats. In addition to the computer-selected matrix, the module also shows the potentiometer or programmable settings that most closely match the targets. The values of the base matrix are shown as well as the variable output, gain and slope or the current settings. The hearing professional can decide to select another base matrix or trimmer settings for the patient. These alternate selections are available by selecting "More" from the Hearing Aid Selection screen (Figure 10, lower right). The data base search of matrices brings up one "Best Fit" and several others whose frequency response also matches the targets, but whose compression characteristics may vary. Because of the active trimmers and wide range of adjustments of the programmable hearing aids more than one base matrix may fit the patient's hearing loss. These, plus every available matrix, are retrieved from the "More" menu. The clinician can select any of these additional matrices as the basis for the hearing aid selection. The "Best Fit" selected by the PFS can always be reasserted by accessing the "Best Fit" function.

Electronic Order Form

Once the desired matrix and trimmer or program settings have been identified, along with the ear and model to be fitted, clicking the "Order Form" button on the screen opens an electronic order form (Figure 11). From this screen, the clinician may further customize the order and print an order form ready for mailing. All information on the printed order form is also displayed as bar code information on the bottom of the page. The

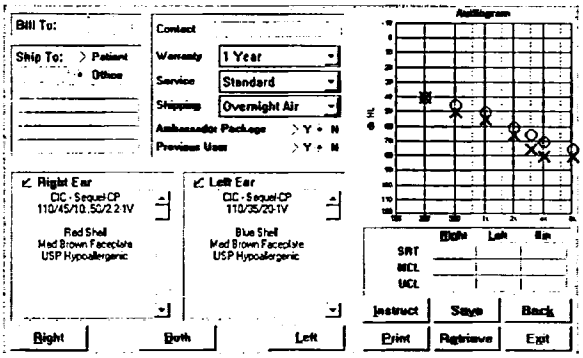

Figure 11. Electronic order form. The Print button will process an order form to be produced. The order form contains all of the ordering, billing and shipping information in both text and bar code format. The bar codes are read at the manufacturing facility permitting direct entry of the order.

bar codes allow the order to be scanned into the computer when the order arrives at Starkey.

REAL EAR FITTING AND VERIFICATION

Overview

Objective verification and real-time real-ear fitting capability has become a necessary part of any hearing aid fitting. With the introduction of recent, nonlinear formulas, (i.e., IHAFF, FDR [i/o], Fig6) come new techniques for real ear measurements. The concepts of multiple input-level targets and SPL-O-Gram displays are an integral part of the Real Ear Verification module of the Professional Fitting System. Utilizing the capability and processing speed of the system, this module provides a highly sophisticated verification method including real-time analysis.

The Real Ear Verification program requires the use of the PFS 6000 real-ear measurement hardware and is accessed by selection from the main PFS pull-down menu. Once the Real Ear Verification program is accessed, the probe microphone system of the PFS 6000 unit is under the control of the PFS software. The real ear test screen is displayed and the clinician is offered a variety of options (Figure 12). If a programmable hearing aid is in place (Figure 13), the clinician can read ("click" read button at upper left of screen) the instrument and the base matrix, ear, and parametric setting data will be transferred to the test screen. The screen displays the multiple input-level targets (50, 70 and 90 dB in this example) created by the selected fitting protocol (IHAFF in this example) (Figure 13). Real ear

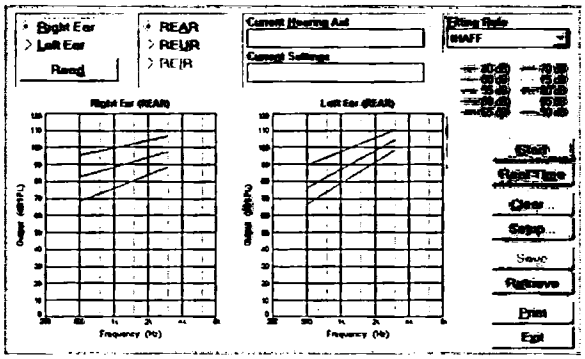

Figure 12. Real ear display and data acquisition screen. In this example, real ear targets for soft, average and loud speech, developed by the IHAFF protocol and loudness growth data, are displayed.

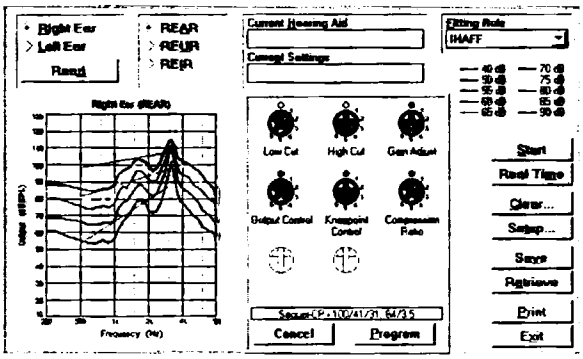

Figure 14. An example of real-time, real-ear aided response collected at five input levels.

measurements can now take place using a wide range of input levels and the real ear curves can be evaluated against the targets (Figure 14). While the real ear curves are being displayed, adjustments to the hearing aid will be immediately reflected in the display. This technology enables the clinician not only to adjust the hearing aid to match the target values, but to simultaneously elicit subjective comments from the user. Once the hearing aid is tuned to the patient's needs, the verification data are stored for use in follow-up visits. Up to four real ear sessions can be saved per day for a particular patient.

Signal type

PFS uses two types of signals to measure the real ear response: pseudo-random noise and speech-weighted noise. The speech-weighted noise has a composition similar to the average long-term speech spectrum. The pseudo-random noise is a broad-band signal similar to white noise designed to provide very consistent results from real ear measures. Both signals are generated digitally by the PFS. The decision to use broad-band noise rather than a pure-tone sweep was made because the PFS is designed to fit hearing aids incorporating nonlinear signal processing. Hearing aids with nonlinear signal processing use a detection mechanism to control when the hearing aid will begin to compress the signal. A swept pure-tone tests one frequency at a time. Because of this, the frequency response of a hearing aid with nonlinear signal processing is dependent upon the relation between the level of the pure-tone and the compression threshold at any particular frequency. Typically, low frequency gain is less than high frequency gain because of the nature of most hearing loss configurations. Low frequency signals in the environment will not trigger a large amount of compression. If a coupler or real-ear response is measured using swept pure-tones, the hearing aid can go into compression part-way through the sweep, especially when signal levels of 70 dB SPL and higher are used. What happens is that single frequency signals begin to force the hearing aid into compression at some region of the frequency response. Thus, lower frequency signals appear to have more gain compared to higher frequency signals. When multiple level sweeps are used, the hearing aid would appear to have more gain for soft low frequency sounds and less gain for louder low frequency sounds. The response looks much like that of a TILL response where weak input levels result in more low frequency gain than high input levels. This is a measurement artifact known as blooming (Dolan, 1991). The real ear response of the hearing aid can appear to be inappropriate

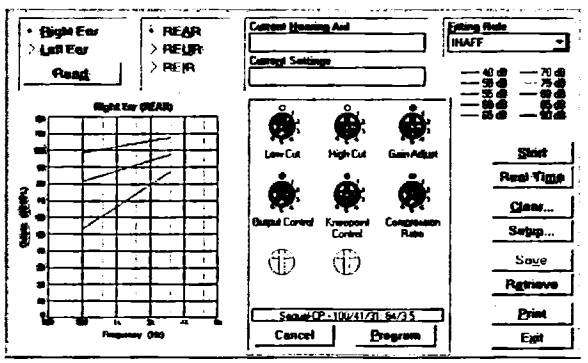

Figure 13. Real ear programming screen showing the adjustable parameters. The real ear aided response is displayed and adjustments made to the hearing aid are reflected in the display in real time format.

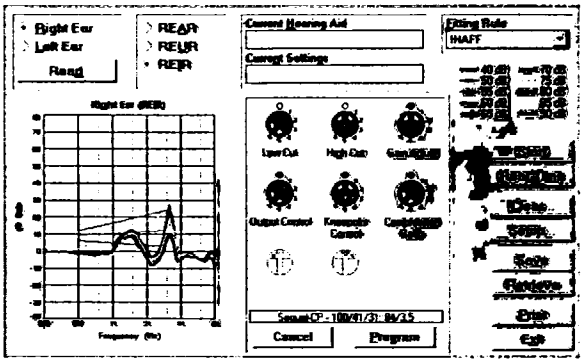

Figure 15. An example of real-time, real-ear insertion responses collected at five input levels.

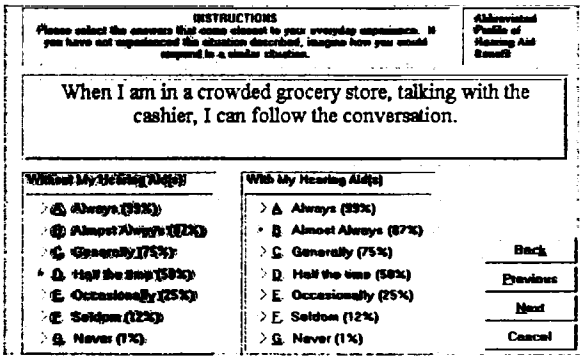

Figure 17. The automated APHAB test. In this example, question 1 of 24 is shown for both unaided and aided listening. The patient can move at his or her own pace and can go back to previous answers if needed.

if inputs become higher than the compression threshold. The PFS avoids the blooming artifact by using broad-band signals specially designed for this measurement approach. The broad-band signals are equalized so that the overall level of the signal is equal to the level for any frequency component in that signal. In general, the root mean square (RMS) output for complex noise is 15-20 dB lower than the same output for pure-tones. Measures made with complex tones often can underestimate the actual performance of a hearing aid compared to pure tones (Stelmachowicz et al, 1990). The equalized SPL feature of the PFS permits accurate measures of nonlinear amplification systems by avoiding these measurements artifacts.

Measurement choices

PFS incorporates measures of the real ear aided response (REAR) with output targets created by loudness scaling information. The PFS also has the capability of measuring the real ear insertion response (REIR) in conjunction with real ear, level dependent gain targets (Figure 15). In order to use the REIR feature, it is necessary to first measure the real ear unaided response (REUR). These three methods of measuring the real ear performance are all accessible from the real ear verification screen (upper box; second from the left as shown in Figure 15.

Start

The PFS uses three input level targets: 50 dB, 70 dB and 90 dB SPL. Start is an automatic feature that allows the clinician to quickly test all three levels and obtain real ear responses to compare to the target values. To access this feature "click" the Start button and the levels selected in the Setup menu will be tested (Figure 15, right side). These three responses are digitized and stored

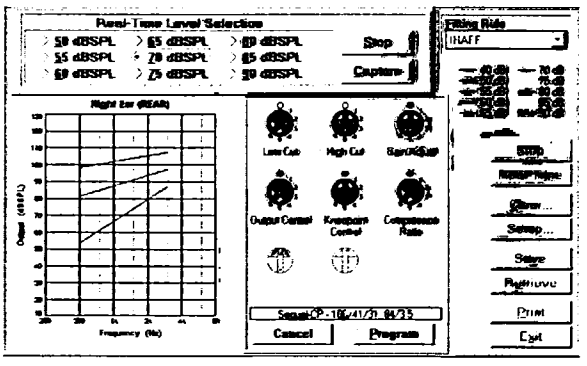

Figure 16. Real-time real ear data acquisition screen. Real time level selection control panel is accessed by "clicking" on the Real Time button. The control panel allows the real-time signal levels to be changed and the data "captured" in computer memory.

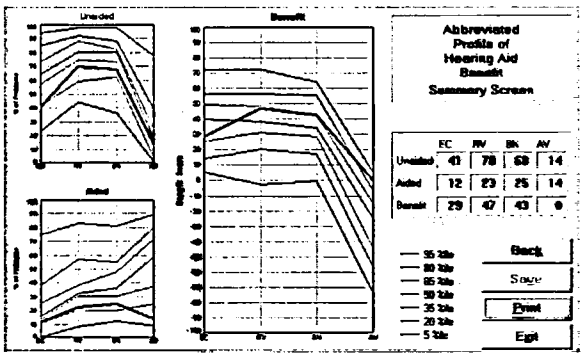

Figure 18. The APHAB summary screen. (See text for details).

off-line and then displayed as a group. The clinician has the option to increase or decrease the number of different levels measured using the "Start" feature. In this way an entire family of frequency responses based on several input levels can be measured with one keystroke.

Real time

When measures are to be made in real time, a signal presentation and capture menu is presented to guide the clinician (Figure 16, top). The clinician can select the signal level, observe the real time response and then by "clicking" the "Capture" button, digitize and store the response for display. Other signal levels can be selected and "captured" in real time without pausing the signal. If adjustments need to be made to the hearing aid, these can be accomplished during signal presentation to view the actual, real-time changes that occur in the patient's ear. Once the change has been made, the resultant real ear curve can be "captured" and displayed. One curve for each of ten signal levels can be displayed on a single chart. The PFS offers the clinician the ability to display any group of curves from those captured in real time.

APHAB

In addition to real-time, real-ear measurement and verification, the PFS offers the hearing professional a subjective measure of hearing aid benefit; the Abbreviated Profile of Hearing Aid Benefit (APHAB). The APHAB was developed by researchers at the University of Memphis (Cox and Alexander, 1995). This 24-item questionnaire asks the patient to rate the relative ease or difficulty of communicating in each of four situations:

1. Ease of Communication (EC) - The effort involved in communication under relatively easy listening conditions.
2. Reverberation (RV) - Speech understanding in moderately reverberant rooms.
3. Background Noise (BN) - Speech understanding in the presence of multitalker babble or other environmental competing noise.
4. Aversiveness of Sounds (AV) - Negative reactions to environmental sounds.

The APHAB was normed on successful hearing aid users and the data for each individual patient can easily be compared to these norms. PFS presents this test in an online mode where the patient answers each question directly from the computer (Figure 17). It is also set up to easily enter data acquired manually from the APHAB score sheet. The APHAB summary screen displays the unaided profile (upper left), the aided profile (lower left) and the benefit profile (right graph). Colored lines on the graphs represent the normal percentiles (5% to 95%)and the results for a patient are overlaid in black. A numeric display (table to the right) is included for easy tabulation of the results (Figure 18). More information about the APHAB can be found in Valente and Van Vliet (1997).

CONCLUSIONS

The PFS 6000 system is designed to assist the hearing professional to select and fit hearing aids that utilize nonlinear signal processing. As an educational tool, it can help the professional understand the complex interactions among compression parameters. It can also help the hearing professional counsel the patient with hearing loss about the ways compression amplification can meet their needs. In the near future, as Starkey incorporates additional hearing instruments into its programmable product line, the PFS will accommodate these new products and technologies by simple software upgrades which can be accomplished in the hearing professional's office.

Starkey Laboratories offers classes in the use of the PFS6000 system, the Sequel product series and the programmable line of hearing solutions.

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